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Variations Observed in the AC Generator Signal Period of a Sea King Helicopter

D.M. Blunt

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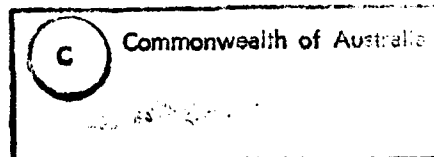
Variations Observed in the AC Generator Signal Period of a Sea King Helicopter

D.M. Blunt

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ABSTRACT

General Document

The AC generator in the Sea King helicopter can be used as a convenient source of a tachometer signal from the main rotor gearbox, thus enabling synchronous vibration signal averages to be calculated for every shaft in the gearbox. The signal averaging software developed by ARL determines the shaft speeds by measuring the tachometer signal period. Variations in the tachometer signal period not caused by changes in gearbox speed will affect the accuracy of the vibration signal averages. An examination has been made of the AC generator signal of a Sea King helicopter recorded on a Brüel & Kjær 4 channel FM tape recorder (model 7003). The results show that the signal averaging software measures short term period variations (from one period to the next) in the AC generator signal of up to ~2% of the mean period. It was found that while most of this variation probably arises from noise present in the recording environment, a considerable proportion comes from noise introduced through the tape recording and filtering processes

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Contents

1. Introduction

Synchronous signal averaging is a vibration analysis technique that effectively extracts that part of the overall vibration signal coming from a particular shaft in a multi-shaft gearbox. The technique requires a tachometer signal so that the vibration signal can be sampled at a rate synchronous with the shaft rotational frequency.

In the Sea King, and most other helicopters, the main AC electrical generators are directly geared to the main rotor gearbox, causing the AC frequency to follow the gearbox speed variations. This allows the AC signal to be used as a tachometer signal and enables the speed of every shaft in the gearbox to be determined.

Variations in the tachometer signal frequency not caused by gearbox speed fluctuations, however, will affect the accuracy of the signal averaging technique. Such variations may come from several sources, including: noise in the AC signal, noise introduced through tape recording and play-back, errors in the tachometer frequency measurement, etc. These unwanted variations need to be minimised, but recognising that they cannot be completely eliminated, an estimation of their magnitudes for a typical helicopter gearbox tachometer signal will provide an appreciation of the problem. Such an estimation will also be useful in the assessment of new signal averaging techniques which may be sensitive to noisy tachometer signals.

This report presents the results from an investigation into variations observed in the period of the AC signal of a RAN Sea King helicopter, and reference signals from a digital signal generator, as measured using the ARL-developed signal averaging software.

2. Tachometer Signal Period Measurement Method

The ARL signal averaging software uses the tachometer signal period as the gearbox speed reference unit when performing a synchronous signal average. That is, the rotational speed of the shaft of interest is calculated from, and updated, every tachometer signal period.

The signal averaging technique involves the following steps:

    a)   Sample the tachometer and vibration signal simultaneously.

    b)   Measure the tachometer signal periods.

    c)   Use the tachometer signal period information, and the ratio of the shaft frequency to tachometer frequency, to digitally re-sample the vibration data at a rate synchronous with the shaft speed. The re-sampled vibration data will then consist of exactly N samples per revolution of the shaft, where N is an integer (usually 512, 1024 or 2048 to facilitate FFT calculations).

d) Average X groups of N samples in a group-wise manner to produce the signal average, where X is an integer (usually > 400). That is, average the first sample in each group to produce the first point in the signal average, average the second sample in each group to produce the second point in the signal average, etc. The result is a signal corresponding to the vibration coming from one revolution of the shaft.

The tachometer signal periods are measured by counting the number of sample periods that occur between the negative-to-positive zero-crossings of the signal. As the zero-crossings nearly always fall between two samples, except on the rare occasions when the signal is sampled exactly on the zero-crossing, the partial sample periods that occur here are linearly interpolated from the sample values in question, as shown in the diagram below.
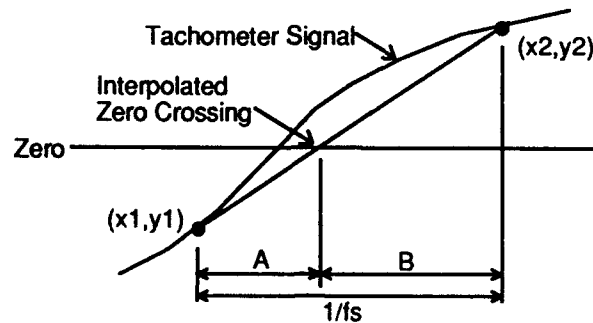
$$A = \frac{-y_1}{(y_2 - y_1)} \times \frac{1}{f_s}$$

$$B = \frac{y_2}{(y_2 - y_1)} \times \frac{1}{f_s}$$

3. Signal Period Measurements

In summary, signal period measurements were made from:

a) Reference sine and square wave signals from a digital signal generator (Analogic Data Precision Polynomial Waveform Synthesizer Model 2020).

b) The signals in (a) recorded on two different, but compatible, 4 channel FM tape recorders (Brüel & Kjær Models 7003 and 7006).

c) The AC generator signal of a Sea King helicopter recorded on a 4 channel FM tape recorder (Brüel & Kjær Model 7003). Tape 1/88 of gearbox WAA 202.

Both tape recorders were operated at a tape speed of 381 mm/s (15 ips). The recorder characteristics at this speed are set out in Table 1 [Refs. 1 & 2].

Table 1. Brüel & Kjær FM Tape Recorder Characteristics
(Models 7003 & 7006)

Model	Signal / Noise	-1 dB Bandwidth (Hz)
7003	44 dB	0 - 10000 DC coupled
		8 - 10000 AC coupled
7006	44 dB	0 - 12500 DC coupled
		4 - 12500 AC coupled

The signal period measurements were made on the ARL portable vibration analysis system. This consists of a Dolch 486 portable computer with a 16 channel Onsite Instruments Techfilter card and an 8 channel Data Translation DT 2821-G-8DI card with a 12 bit analogue-to-digital converter (ADC). The input signals pass through a channel break-out box with 16 BNC connectors to the filter card inputs. Each channel can be individually low-pass filtered, albeit at the same cut-off frequency, or can bypass the filter stage. The first 8 channels of the filter card outputs are connected to the 8 input channels of the ADC card where they are amplified (gains of 1, 2, 4 and 8) and sampled.

In practice it is usual to not filter the tachometer signal as it normally only contains one (low) frequency component, and this was the method adopted in this investigation. Additionally, however, the signal from (c) was filtered to remove a small third harmonic component to see what affect this would have on the results.

All signals were sampled at 40,000 Hz.

3.1. Direct Reference Signals

Sine wave and square wave signals were chosen as the reference signals so as to emulate as closely as possible the two most common types of tachometer signals encountered; AC generator signals, and pulse-type signals. Both reference signals had peak amplitudes of 0.5 Volts and frequencies of 400.937 Hz. This frequency was chosen as it was a signal generator setting conveniently close to the nominal aircraft AC supply frequency (400 Hz), yet was not a factor of the sampling frequency (40,000 Hz), as this would have artificially affected the results.

The periods of these signals, as measured by the signal averaging software, are shown in Figure 1, and the statistical results can be found in Table 2.

Table 2. Direct Reference Signal Period Statistics*

Signal	Min. Period (ms)	Max. Period (ms)	Max. Variation+ (ms)	Mean (ms)	St. Deviation (ms)
Sine	2.4920	2.4963	0.0038	2.4942	0.0008
Square	2.4751	2.5000	0.0249	2.4941	0.0097

* Over 200 signal cycles.
+ Variation from one cycle to the next.

Period (ms)　　　　　　TACHOMETER SIGNAL PERIOD

```
Mean = 2.4942 ms        Max  = 2.4963 ms        Min  = 2.4920 ms
RMS  = 0.0008 ms        Kurtosis = 2.3507
Max. Variation over 1 cycle = 0.0038 ms (79 Cycle)
```
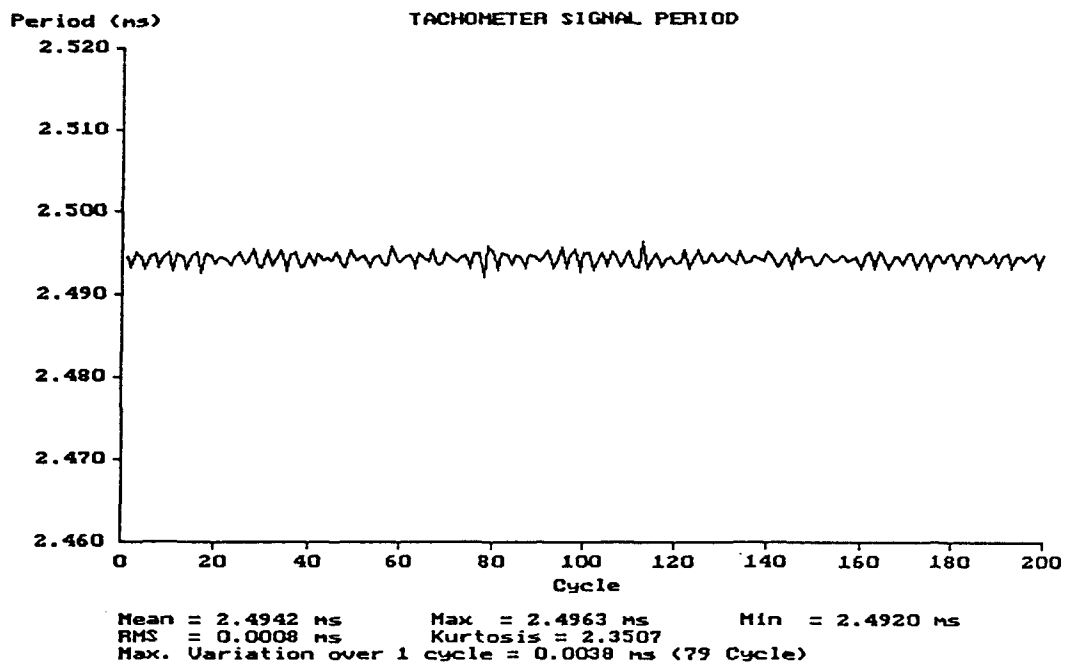
Figure 1a:　Direct sine wave signal period

Period (ms)　　　　　　TACHOMETER SIGNAL PERIOD

```
Mean = 2.4941 ms        Max  = 2.5000 ms        Min  = 2.4751 ms
RMS  = 0.0097 ms        Kurtosis = 2.6478
Max. Variation over 1 cycle = 0.0249 ms (177 Cycle)
```

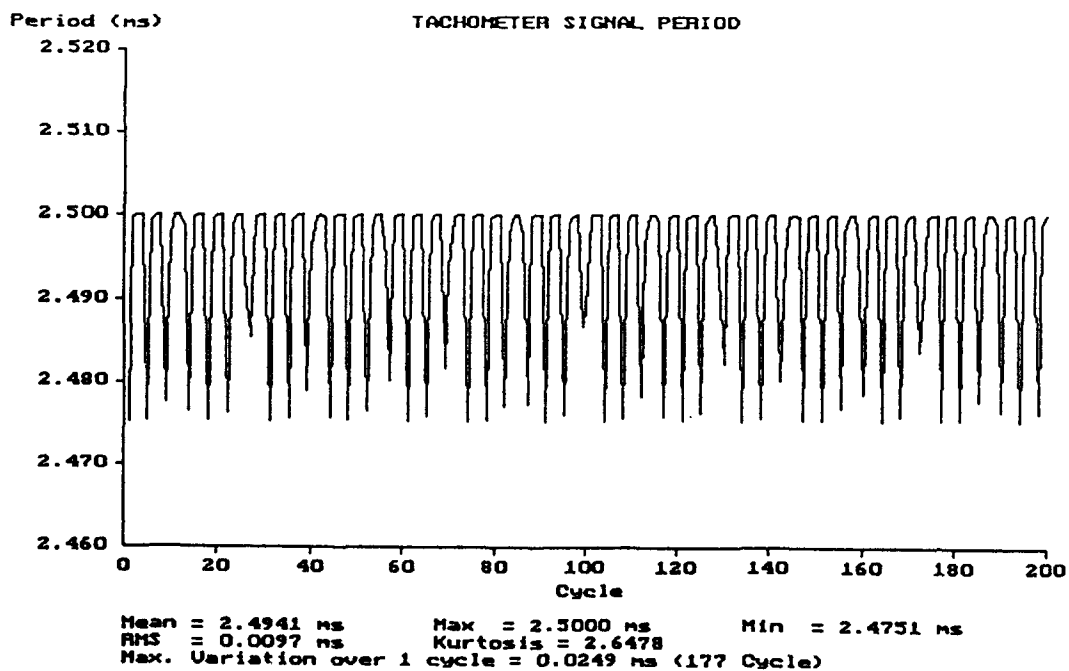*Figure 1b:　Direct square wave signal period*

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3.2. Recorded Reference Signals

Recordings of the reference signals were made on both tape recorders using three methods: AC coupling, DC coupling, and FM flutter compensation (7006 model only). Flutter compensation is claimed to reduce flutter caused by sources external to the drive mechanism by 35 dB up to 500 Hz [Ref. 2].

The statistical results for all measurements taken can be found in Tables 3 and 4. These include measurements of the AC coupled recordings made on the model 7003 recorder and played back on the model 7006 recorder, and vice-versa. Plots of the results obtained from each method and recorder were found to be very similar and consequently only the plots of the AC coupled recordings on the 7003 recorder are shown here, see Figure 2.

Table 3. Recorded Reference Sine Wave Signal Period Statistics*

Recorded	Played Back	Coupling	Min. Period (ms)	Max. Period (ms)	Max. Variation[+] (ms)	Mean (ms)	Standard. Deviation (ms)
7003	7003	AC	2.4847	2.5039	0.0152	2.4939	0.0033
7006	7006	AC	2.4866	2.5010	0.0108	2.4940	0.0030
7003	7006	AC	2.4772	2.4989	0.0160	2.4882	0.0039
7006	7003	AC	2.4939	2.5059	0.0086	2.4999	0.0022
7006	7006	DC	2.4854	2.5026	0.0132	2.4941	0.0033
7003	7003	DC	2.4868	2.5003	0.0135	2.4941	0.0028
7006	7006	AC / Flutter Comp.	2.4853	2.5017	0.0100	2.4942	0.0029
7006	7006	DC / Flutter Comp.	2.4850	2.5012	0.0113	2.4940	0.0026

* Over 200 signal cycles.
+ Variation from one cycle to the next.

Table 4. Recorded Reference Square Wave Signal Period Statistics*

Recorded	Played Back	Coupling	Min. Period (ms)	Max. Period (ms)	Max. Variation[+] (ms)	Mean (ms)	Standard Deviation (ms)
7003	7003	AC	2.4886	2.4978	0.0046	2.4940	0.0017
7006	7006	AC	2.4884	2.4985	0.0057	2.4940	0.0021
7003	7006	AC	2.4832	2.4933	0.0076	2.4882	0.0024
7006	7003	AC	2.4956	2.5041	0.0029	2.5000	0.0015
7006	7006	DC	2.4888	2.4984	0.0049	2.4941	0.0020
7003	7003	DC	2.4895	2.4972	0.0042	2.4940	0.0015
7006	7006	AC / Flutter Comp.	2.4882	2.4990	0.0049	2.4941	0.0021
7006	7006	DC / Flutter Comp.	2.4880	2.4984	0.0059	2.4941	0.0020

* Over 200 signal cycles.
+ Variation from one cycle to the next.

Period (ms)   TACHOMETER SIGNAL PERIOD

Mean = 2.4939 ms   Max = 2.5039 ms   Min = 2.4847 ms
RMS = 0.0033 ms   Kurtosis = 2.9080
Max. Variation over 1 cycle = 0.0152 ms (131 Cycle)
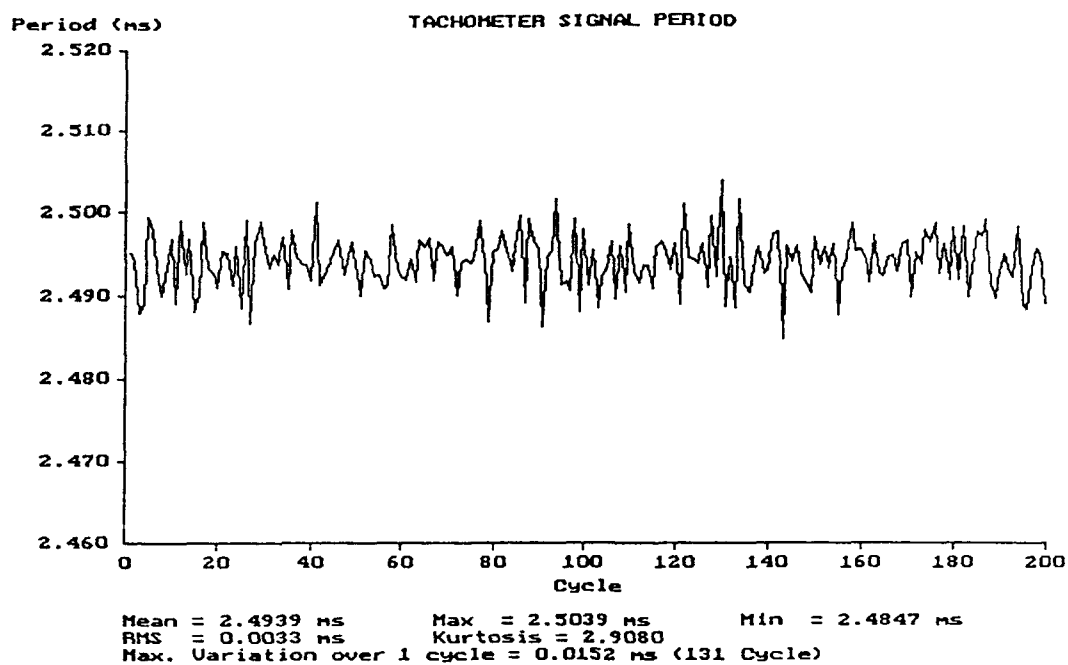
Figure 2a: Signal period of sine wave recorded/played B&K7003 AC coupling

Period (ms)   TACHOMETER SIGNAL PERIOD

Mean = 2.4940 ms   Max = 2.4978 ms   Min = 2.4886 ms
RMS = 0.0017 ms   Kurtosis = 2.9527
Max. Variation over 1 cycle = 0.0046 ms (4 Cycle)

Figure 2b: Signal period of square wave recorded/played B&K7003 AC coupling

3.3. Sea King AC Generator Signal

Oscilloscope observations of the recorded Sea King AC generator signal have shown that it is essentially a sine wave with a frequency varying from 411 Hz to 417 Hz, depending on the torque setting, but that it also has a small third harmonic component present. The period of the signal, as played back on the model 7006 recorder, was measured over 2000 signal cycles for three torque settings (50%, 75%, 100%) with and without low-pass filtering by the Techfilter card to remove the third harmonic (800 Hz cut-off freq). Approximately the same section of the recording, as determined by the tape counter, was used for the filtered and unfiltered cases, but there will have been slight differences between the tape starting positions. The statistical results are detailed in Tables 5 and 6.

Plots were made of all the period measurements and, while there were significant differences between the filtered and unfiltered cases, the plots for all three torque settings within each case were found to be very similar. Consequently, only the plots of the 50% torque results have been included here and are shown in Figures 3 and 4. Part (a) of each figure shows the period measurements over 2000 cycles, or ~5 seconds, while part (b) shows the period measurements over just 200 cycles, or ~0.5 seconds.

Table 5. Unfiltered Sea King Generator Signal Period Statistics*

Torque	Min. Period (ms)	Max. Period (ms)	Max. Variation+ (ms)	Mean (ms)	St. Deviation (ms)
50%	2.4094	2.4536	0.0164	2.4310	0.0061
75%	2.3927	2.4312	0.0307	2.4115	0.0054
100%	2.3798	2.4120	0.0204	2.3973	0.0047

* Over 2000 signal cycles.
+ Variation from one cycle to the next.

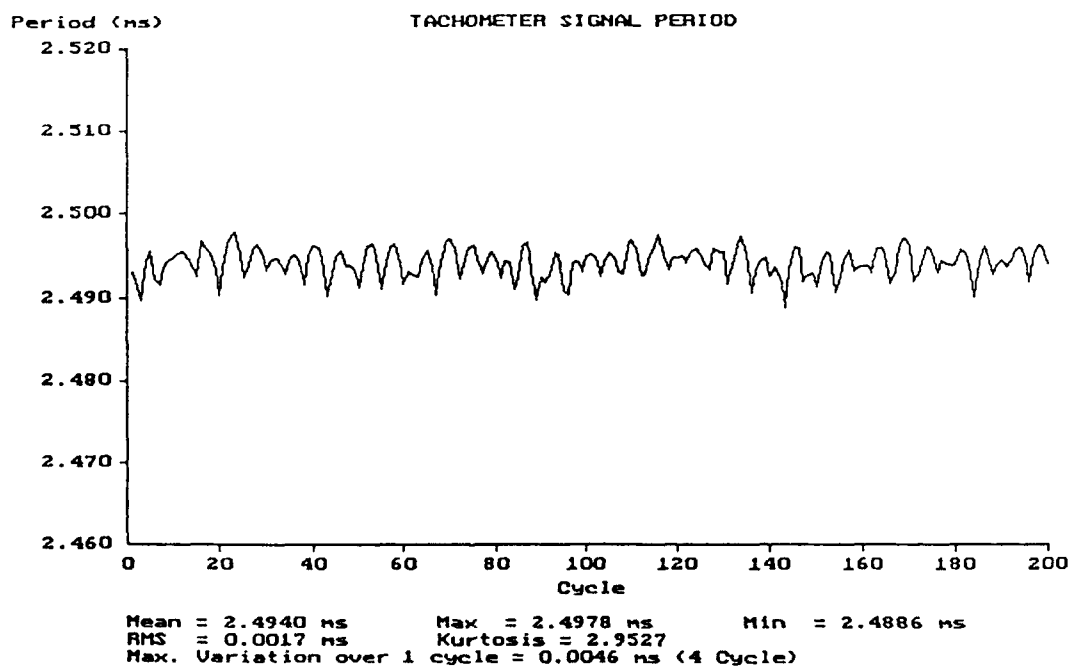### Table 6. Filtered Sea King Generator Signal Period Statistics*

Torque	Min. Period (ms)	Max. Period (ms)	Max. Variation+ (ms)	Mean (ms)	St. Deviation (ms)
50%	2.4044	2.4630	0.0431	2.4338	0.0115
75%	2.3872	2.4476	0.0456	2.4182	0.0114
100%	2.3759	2.4324	0.0430	2.4035	0.0113

* Over 2000 signal cycles.
+ Variation from one cycle to the next.

Period (ms) TACHOMETER SIGNAL PERIOD

2.460
2.450
2.440
2.430
2.420
2.410
2.400
0   200   400   600   800   1000 1200 1400 1600 1800 2000
Cycle

Mean = 2.4310 ms   Max = 2.4536 ms   Min = 2.4094 ms
RMS = 0.0064 ms   Kurtosis = 2.9653
Max. Variation over 1 cycle = 0.0164 ms (1659 Cycle)
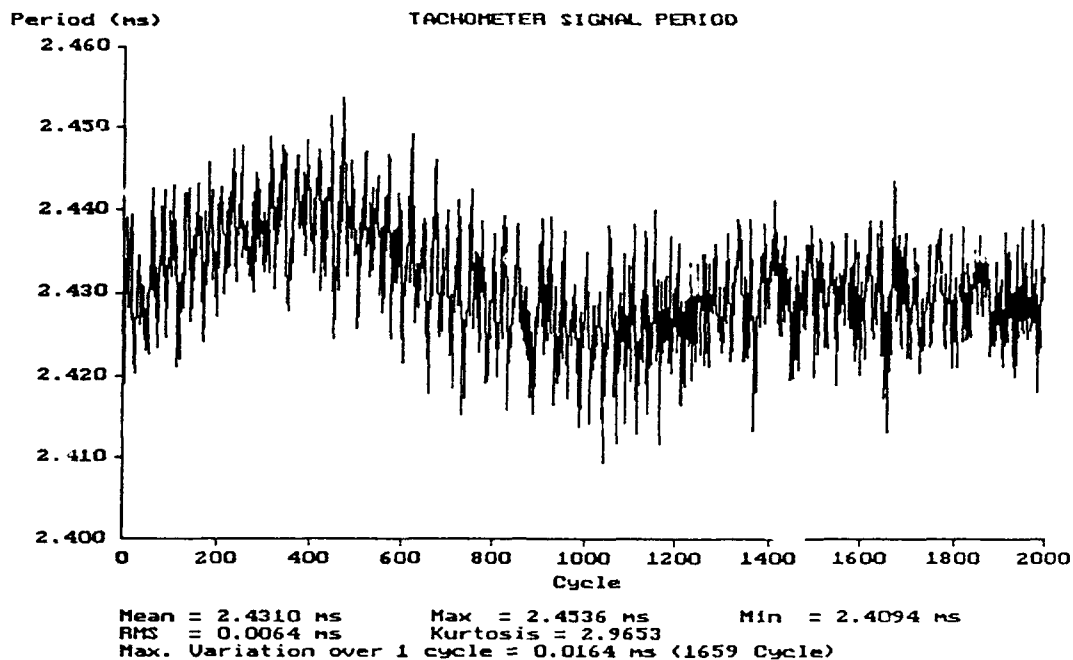
Figure 3a: Sea King AC generator signal period over 2000 cycles 50% torque

Period (ms) TACHOMETER SIGNAL PERIOD

2.460
2.450
2.440
2.430
2.420
2.410
2.400
0   20   40   60   80   100 120 140 160 180 200
Cycle

Mean = 2.4327 ms   Max = 2.4438 ms   Min = 2.4192 ms
RMS = 0.0054 ms   Kurtosis = 2.4621
Max. Variation over 1 cycle = 0.0147 ms (117 Cycle)
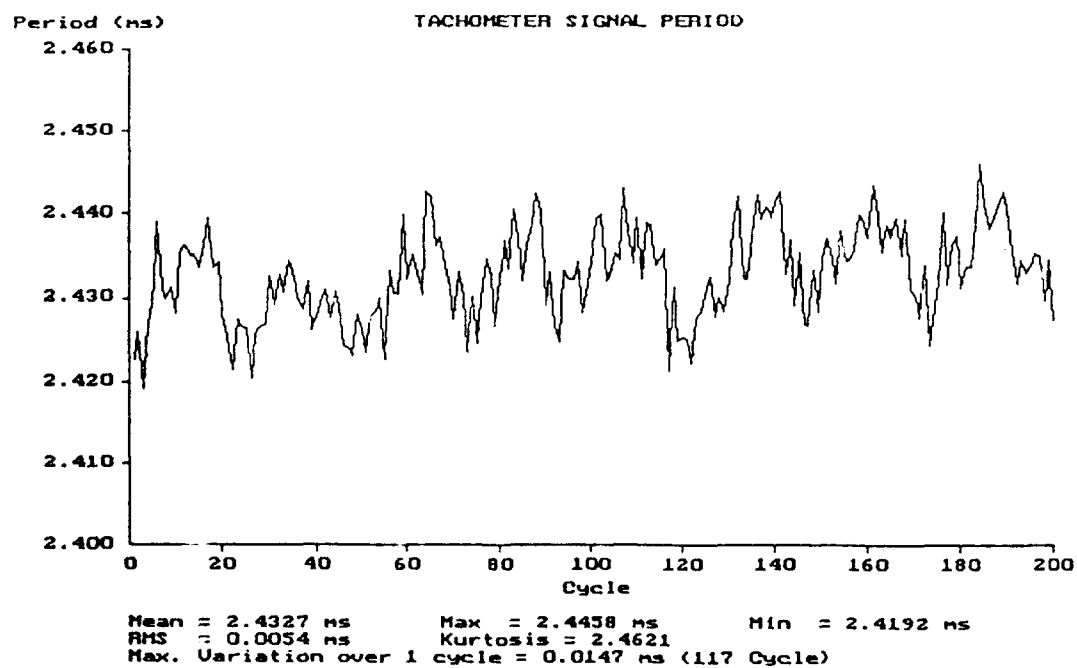
Figure 3b: Sea King AC generator signal period over 200 cycles 50% torque

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Period (ns)

TACHOMETER SIGNAL PERIOD

```
Mean = 2.4338 ns        Max  = 2.4630 ns        Min  = 2.4044 ns
RMS  = 0.0115 ns        Kurtosis = 2.1335
Max. Variation over 1 cycle = 0.0431 ns (922 Cycle)
```
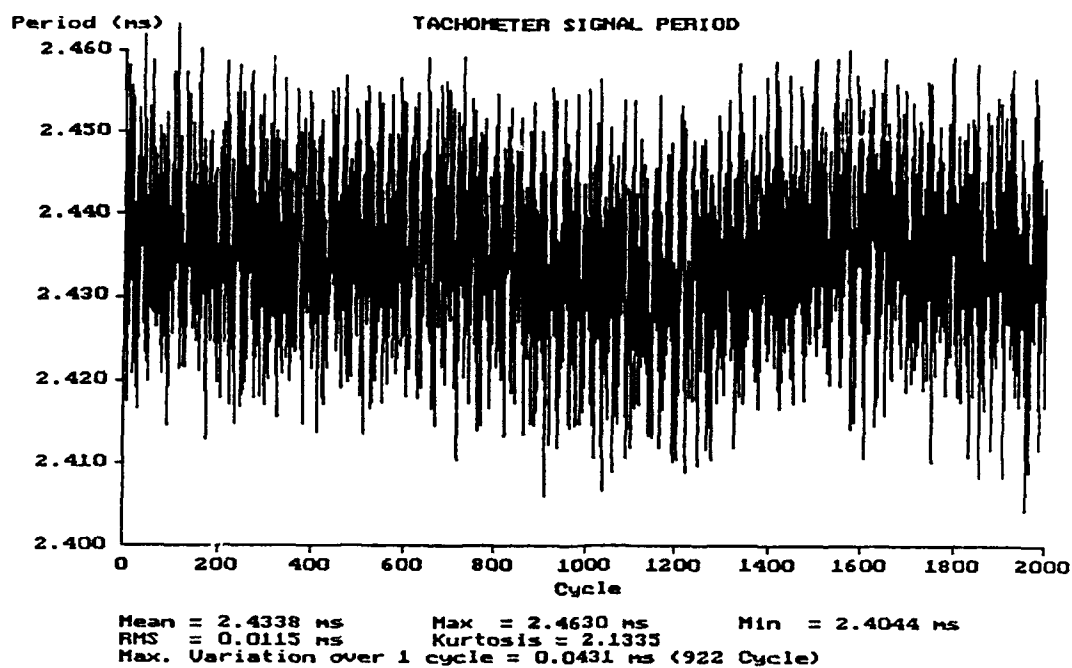
Figure 4a: Filtered Sea King AC generator signal period 2000 cycles 50% torque

Period (ns)

TACHOMETER SIGNAL PERIOD

```
Mean = 2.4355 ns        Max  = 2.4630 ns        Min  = 2.4129 ns
RMS  = 0.0110 ns        Kurtosis = 2.2552
Max. Variation over 1 cycle = 0.0406 ns (7 Cycle)
```
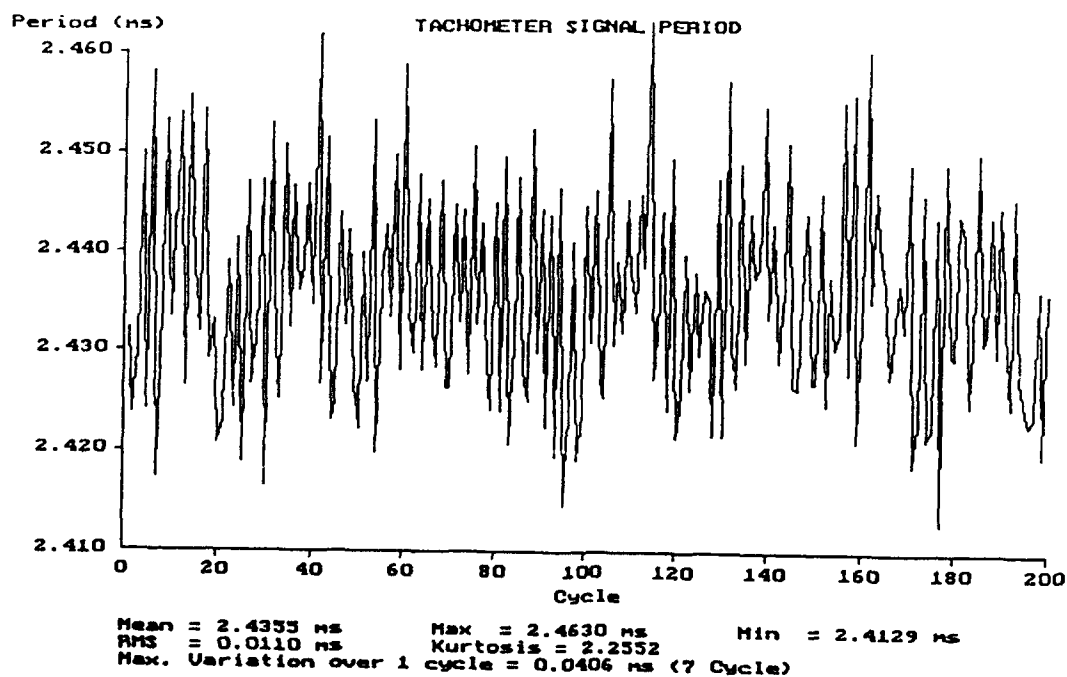
Figure 4b: Filtered Sea King AC generator signal period 200 cycles 50% torque

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4.   Observations

4.1.   Direct Reference Signals

Since the reference sine wave has an approximately linear slope in the vicinity of the zero-crossing, it was expected that the linear interpolation errors would be very small for this signal. This was borne out by the results with the maximum variation over one cycle of just 3.8 µs (0.15% of the mean period), and a standard deviation of 0.8 µs (0.03%), the smallest results for all the measured signals. These results are, however, still significantly greater than the theoretical errors for this signal, which are detailed in Appendix A.

The reasons for this are not known but may include: inadequate noise isolation between the signal generator and the filter card, noise introduced by the filter card, and numerical error in the period calculation (double precision – 8 byte – floating point arithmetic was used so this should be small).

The much larger variation present in the period measurements of the reference square wave can be explained by the short rise time of the signal, which was measured with a CRO to be ~10 ns. As this is much less than the sample period of 25 µs, the linear interpolation technique will fail, and it is therefore possible for the period measurements to be in error by as much as one whole sample period. The maximum variation measured over one cycle of 2.49 µs (1.00% of the mean period) approaches this value, and the standard deviation is similarly large at 9.7 µs (0.39%).

4.2.   Recorded Reference Signals

These results show that the FM recording and play-back of the signal significantly increases the period variation of the reference sine wave over the direct signal measurements. The maximum variation over one cycle increases to 16.0 µs (0.64% of the mean period), and the average standard deviation for all eight measurements is ~3.0 µs (0.12%). This increase in noise may come from a number of sources including: tape quality, recording and play-back head quality, FM modulation and demodulation errors, etc.

The results for the reference square wave signal, however, show a reduction in the period variation. The maximum variation over one cycle decreases to 7.6 µs (0.30% of the mean period), and the average standard deviation for all eight measurements is ~1.9 µs (0.08%). This can be accounted for by the limited bandwidth of the recorders (see Table 1) effectively filtering out the higher harmonics of the square wave signal, increasing the rise time (measured with a CRO to be ~40µs) to more than one sample period, thus improving the ability of the linear interpolation technique to determine the actual zero-crossing.

The recorded square wave results are, in fact, slightly better than the recorded sine wave results. This indicates that a steeper signal slope, within the limits of the sampling period resolution, gives a better zero-crossing detection, as would be expected.

No significant differences are apparent between the results for the various recording coupling methods, nor between which machine the signal was recorded or played back on. However, the results were obtained in the laboratory situation, and it is possible that the FM flutter compensation on the model 7006 tape recorder may improve a field (helicopter) recording.

4.3. Sea King AC Generator Signal

While the Sea King AC generator signal is essentially a sine wave, the amount of short term variation evident is much larger than that of the recorded reference sine wave signal. The maximum variation in the unfiltered signal period is 30.7 μs (1.27% of the mean period), and the average standard deviation is ~5.5μs (0.23%), both approximately double the recorded reference sine wave results.

This is much greater than would be expected from gearbox/rotor speed fluctuations alone due to the inertia of the rotating parts. The gearbox/rotor speed variations are more likely to be represented by the longer term variation discernible in Figure 3a. The source of the short term variation is therefore probably noise. This is not unexpected due to the harsh environment under which the signal was recorded; airborne in a helicopter, where the background cabin vibration and possible stray electromagnetic interference will have affected the recording process to some degree.

The decrease in the standard deviation of the period variation from 6.4 μs (0.26% of the mean period) at 50% torque to 4.7 μs (0.20%) at 100% torque provides some evidence that the amount of short term variation decreases slightly with increasing torque. Note, however, that the maximum variation over one cycle does not show a similar trend (16.4 μs – 50%, 30.7 μs – 75%, 20.4 μs – 100%), so this may be unreliable.

Filtering the signal to remove harmonics actually increases the magnitude of the period variation rather than decreasing it. The maximum variation over one cycle increases to 45.6μs (1.89% of the mean period), and the standard deviation approximately doubles to ~11.4 μs (0.47%). This is probably due to the switched capacitor design of the filter affecting the 'smoothness' filter output.

4.4. Periodicity of Signal Period Measurements

There appears to be some periodicity to the signal period variations as plotted in Figures 1a, 1b, 2a, 2b and 3b.

The variation in the reference sine wave period seen in Figure 1a appears to recur approximately every three cycles. However, as established in Appendix A, the magnitude of these variations is larger than the theoretical sources of error considered, and so must therefore arise from a source or sources unknown. The period variations of the recorded version of this signal seen in Figure 2a exhibit a residual periodicity from the original signal, but are dominated by a more random variation introduced by the tape recording process.

The reference square wave signal period variations, as seen in Figures 1b and 2b, clearly recur just over every four cycles. This can be explained by the

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accumulating error caused by the interpolation problem described in section 4.1. The ratio of the sampling frequency to signal frequency is:

$$\text{Samples per signal period} = \frac{40000}{400.937} = 99.7663$$

So if the sampling is started at the 0th zero-crossing, then the first zero crossing will be detected on the 100th sample and be in error by:

$$\text{Error} = 100 - 99.7663 = 0.2337 \text{ samples}$$

This error will accumulate and once it reaches a whole sample period will result in a short period measurement of 99 samples, or 2.475 ms. This will recur at a rate, which is clearly visible in the plot, of:

$$\text{Error recursion rate} = \frac{1}{0.2337} = 4.279 \text{ signal periods}$$

The periodicity in the Sea King period variations is more complex and the causes are not clear. The major recursion rate seen in Figure 3b is approximately 25 cycles. This corresponds very closely to the ratio of the AC generator signal frequency to the crown-wheel shaft rotational frequency, which is:

$$\text{AC to Crownwheel ratio} = \frac{3}{1} \times \frac{111}{42} \times \frac{129}{40} \approx 25.57$$

and so may be the source of this periodicity, but it is not conclusive.

5.   Concluding Remarks

Using the ARL portable vibration analysis system, with an ADC sampling frequency of 40,000 Hz, the period measurements of the 0.5 V_{peak} 400.937 Hz reference sine and square wave signals have shown (percentages quoted are with respect to the measured mean period):

a)   The smallest amount of signal period variation was in the measurements of the direct sine wave signal, with a maximum variation of 3.8 μs (0.15%) and a standard deviation of 0.8 μs (0.03%), but this was still an order of magnitude or more greater than the theoretical errors for the period measurement technique.

b)   Period measurement of square wave, or pulse type, tachometer signals will contain significant error, up to one sample period (25μ s), if the sampling period is less than the rise time of the signal.

c)   Recording the signals introduces noise that increases the amount of signal period variation measured. For the reference sine wave the maximum variation increased to 16.0 μs (0.64%) and the standard deviation rose to ~3.0 μs (0.12%).

d)   There would appear to be no benefit to using one recording coupling method over another in the laboratory situation.

Examination of the Sea King AC generator signal has revealed:

a)   There is a significantly larger amount of short term variation in the period of this signal than in the recorded reference sine wave signal, probably caused by noise introduced by the harsh recording environment. The maximum variation and standard deviation in this case are 30.7 μs (1.27%) and ~5.5 μs (0.23%) respectively.

b)   Filtering the signal introduces more noise, probably due to the switched capacitor filter operating characteristic. The maximum variation and standard deviation increased to 45.6 μs (1.89%) and ~11.4 μs (0.47%) respectively.

These results indicate that, in practice, a certain amount of noise will always be present in the tachometer signal from a helicopter gearbox. For the Sea King this noise may produce a maximum tachometer signal period variation of up to 2% of the mean period for a nominally constant speed gearbox. All signal averaging techniques must therefore be capable of tolerating these noisy tachometer signals.

6.   References

1.   Brüel & Kjær, Instruction Manual for Types 7003 and 7004 Tape Recorders, Document 033-0012, 1976.

2.   Brüel & Kjær, Instruction Manual for Types 7005 and 7006 Tape Recorders, Document BE 0645-12, 1983.

3.   Analogic Corp. (Data Precision Division), User Manual for the Polynomial Waveform Synthesizer Models 2020 and 2000, Document 82-5016 Rev C.

4.   Data Translation Inc., User Manual for DT2821 Series Analogue & Digital I/O Boards, Document UM-05073-H, 1990.

5.   Onsite Instruments Inc., Techfilter Owners Manual.

Appendix A

Theoretical Sine Wave Period Measurement Errors

The following calculations were performed to gain a rough estimate of the errors involved in the measurement of the reference sine wave signal period sampled at 40,000 Hz using the ARL signal averaging software.

$$\text{Reference sine wave} = V(t) = 0.5 \times \sin(2\pi(400.937)t)$$

Each type of error has been considered in isolation from the others, but in reality the total error will be the result of a complex interaction between them.

Linear Interpolation Error
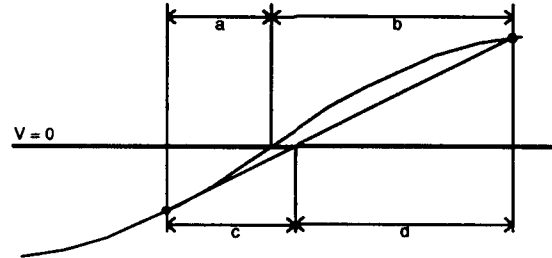
Using

$$\frac{c}{d} = \frac{\sin(2\pi fa)}{\sin(2\pi fb)} \qquad \text{and} \qquad T = a + b = c + d$$

the linear interpolation error is

$$Error = c - a = \frac{T\sin(2\pi fa)}{\left(\sin(2\pi fa) + \sin(2\pi f(T-a))\right)} - a \qquad 0 \le a \le T$$

For

$$T = 2.5 \times 10^{-5} \text{ sec}, \ f = 400.937 \text{ Hz}$$

the function has a maximum and minimum of

$$Error \approx \pm 1.59 \times 10^{-9} \text{ sec} \quad \text{at} \quad a \approx 0.211T \quad \text{and} \quad a \approx (1-0.211)T \text{ respectively}$$

Thus the total period measurement error, from one zero-crossing to the next, could be up to twice this value if $a = 0.221T$ at the first crossing, and $a = (1-0.221)T$ at the second crossing, or vice versa. This puts an upper limit on the error magnitude, but the actual error should be somewhat smaller as the ratio of the sampling frequency to signal frequency will prevent a taking on these values at adjacent zero-crossings simultaneously.

> Max. Period Error due to Interpolation $\approx \pm 3.18 \times 10^{-9}$ sec

The maximum change in this error from one period to the next will be limited to twice this value, that is 6.36×10^{-9} sec.

ADC Resolution Error

The DT2821-G-8DI card has a 12 bit ADC which limits the resolution of the sample values.

The ADC has a maximum peak-to-peak input range of 20 Volts at a gain of 1, with gains of 1, 2, 4 and 8 available. The reference sine wave measurements were made with the maximum amplification of 8 reducing the peak-to-peak input range to 2.5 Volts. Thus, in the sample period which occurs at the zero-crossing the sample value will increase by:

$$\Delta x = \frac{A \cdot \sin(2\pi f \Delta t)}{\Delta V / 2^{12}} \qquad \text{where } \Delta V \text{ is the peak to peak ADC range}$$

$$= \frac{0.5 \sin\left(2\pi(400.937)\dfrac{1}{40000}\right)}{2.5 / 4096}$$

$$\approx 52 \text{ ADC units}$$

The inherent quantizing error of ± 0.5 LSB will cause the maximum period measurement error if the samples delineating the zero-crossings at the beginning and end of the signal period are, respectively, at opposite extremes of the error band. That is, the samples marking the starting zero-crossing are both 0.5 ADC units below their true values, and the samples marking the end zero-crossing are both 0.5 ADC units above their true values, or vice versa. The maximum period measurement error will then be:
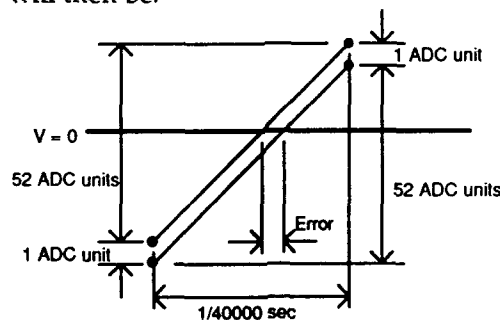
$$\boxed{\text{Max. Period Error due to ADC} = \pm\frac{1}{52} \times \Delta t = \pm\frac{1}{52} \times \frac{1}{40000} \approx \pm\, 4.81 \times 10^{-7} \text{ sec}}$$

The maximum change in this error from one period to the next will be twice this value, that is 9.62×10^{-7} sec. This would happen if, for three consecutive zero-crossings, the first and third were at one extreme of the error band, and the middle was at the other extreme.

Digital Signal Generator Resolution Error

The Analogic Data Precision Polynomial Waveform Synthesizer (Model 2020) is also a 12-bit device, limiting the resolution of the generated signal to discrete values.

The signal generator places one cycle of the desired function into the output memory buffer and then sends this buffer to a 12-bit digital-to-analogue converter (DAC) in an infinite loop to generate the desired signal. It selects the largest integer buffer size, not exceeding the available memory, that can be cycled through at the fastest clock rate in a time not less than the desired signal period. If the buffer size would exceed the available memory at the fastest clock rate, a slower clock rate is used.

The reference signal frequency of 400.937 is achieved by cycling through a buffer of 62354 memory locations at the maximum clock rate of 40 ns.

$$freq = \frac{1}{62354\left(40\times10^{-9}\right)} = 400.937 \text{ Hz}$$

The 12-bit DAC limits the resolution of the voltage 'steps' provided at the generator output. The reference signals have peak amplitudes of 0.5 volts so the voltage 'steps' are therefore:

$$\Delta V = \frac{1.0}{2^{12}} = 2.4414\times10^{-4} \text{ Volts}$$
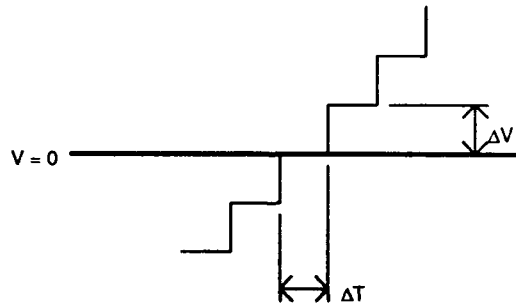
The number of DAC buffer locations that occur for one 'step' in the DAC output value at the zero-crossing should be:

$$\Delta buff = \frac{\Delta t}{\text{clock rate}} \quad \text{where } \Delta t \text{ is the time for one} \Delta V \text{ 'step'}$$

$$= \frac{1}{\text{clock rate}} \times \frac{1}{2\pi f} \sin^{-1}\left(\frac{\Delta V}{A}\right)$$

$$= \frac{1}{40\times10^{-9}} \times \frac{1}{2\pi(400.937)} \sin^{-1}\left(\frac{2.4414\times10^{-4}}{0.5}\right)$$

$$\approx 5 \text{ buffer locations}$$

This represents a maximum period measurement error, ΔT, of:

$$\text{Max. Period Error due to DAC} = \pm\Delta T = \pm\, 5\times\left(40\times10^{-9}\right) = \pm\, 2.00\times10^{-7} \text{ sec}$$

The maximum change in this error, from one period to the next, will be twice this value, that is 4.0×10^{-7} sec.

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The AC generator in the Sea King helicopter can be used as a convenient source of a tachometer signal from the main rotor gearbox, thus enabling synchronous vibration signal averages to be calculated for every shaft in the gearbox. The signal averaging software developed by ARL determines the shaft speeds by measuring the tachometer signal period. Variations in the tachometer signal period not caused by changes in gearbox speed will affect the accuracy of the vibration signal averages. An examination has been made of the AC generator signal of a Sea King helicopter recorded on a Brüel & Kjær 4 channel FM tape recorder (model 7003). The results show that the signal averaging software measures short term period variations (from one period to the next) in the AC generator signal of up to ~2% of the mean period. It was found that while most of this variation probably arises from noise present in the recording environment, a considerable proportion comes from noise introduced through the tape recording and filtering processes

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